Enhancing 3D City Models with Heterogeneous Spatial Information: Towards 3D Land Information Systems

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Abstract. Spatial and georeferenced information plays an important role in urban land management processes such as spatial planning and environmental management. As many of the processes are increasingly coined by participation of and collaboration between multiple stakeholders, a common medium capable of integrating different types and sources of spatial information is necessary. It is argued that 3D city models provide such a framework and medium into which heterogeneous information can be integrated. Therefore, the main research question of this contribution is to identify and develop methods for integrating heterogeneous spatial and georeferenced information into 3D city models in the context of urban land management. We present a prototype 3D Land Information System and a use case for the city centre of Potsdam, Germany. In addition, constraints within administrations regarding the systematic, sustainable use of such a system are discussed.

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1 Introduction

Urban land management encompasses all actions, strategies and plans a city or community undertakes to maintain and develop the city's infrastructure, to monitor and protect its natural resources, to build communities, and find a balance between environmental, economic and social needs. It covers a variety of administrative tasks such as city planning, land-use planning, environmental planning and monitoring, public property management, business promotion, city marketing, and technical infrastructure maintenance. These administrative tasks rely on and produce spatial information relevant for decision-making. However, authorities are not the only stakeholders, nor are they the only users or owners of spatial data used in land management processes. Private companies, such as planning and engineering offices, infrastructure providers, geo-data providers, and the public also use, create, analyse, and provide spatial information for urban land management. Thematically the data covers, amongst other things, plans, environmental data, thematic maps, utility network data, transportation network data, environmental assessment studies, and noise emission maps. Consequently, the overall quantity of spatial data relevant for urban land management increases continuously and, because of the differentiated needs and capabilities of data users, modelling concepts and data structures are often process-, application- and scale-dependent.

The underlying thesis of this contribution is that *semantic 3D city models* (Kolbe 2009) provide an innovative and intuitive framework and medium into which spatial and georeferenced information can be integrated to effectively support communication processes in urban land management. The research is motivated by two main themes: developments in 3D city modelling and the utilization of interactive 3D models in landscape and urban planning. In the scope of 3D city modelling developments in sensor technologies as well as in processing the acquired data have resulted in methods to (semi-) automatically process and derive 3D city objects and 3D city models, respectively (e.g., Rottensteiner et al. 2005; Haala and Brenner 1999; Richman et al. 2005). Consequently, the costs for generating 3D city models have dropped continuously, and, for example, in Germany many communes and administrations have added 3D city models to their local data infrastructures or are planning to in the near future. Parallel to this development, two data models, the City Geography Markup Language (CityGML, Gröger et al. 2008, Kolbe 2009) and the Keyhole Markup Language (KML, Wilson 2008), have evolved as Open GIS standards, which can be used for the storage and exchange of 3D city models. In this contribution the *Level of Detail* (LOD) definitions from the

CityGML specifications are adopted to differentiate between simple block-buildings (LOD1), buildings with differentiated geometries including roof structures (LOD2), and architectural models of buildings (LOD3). Furthermore, CityGML is used to model city objects and plan information.

The second theme, the use of interactive 3D models in spatial and environmental planning, is related to the development of 3D city models. Spatial planning has been one of the drivers for developing tools and methods for the creation and visualization of interactive 3D city and 3D landscape models. Research in this field covers case studies (e.g., Danahy 2005, Lange and Hehl-Lange 2005), the question of the right degree of realism of (geo-)virtual environments and 3D visualizations for planning issues (e.g., Appleton and Lovett 2003, Cartwright et al. 2005), and the development and assessment of technologies and methods (e.g., Ranzinger and Gleixner 1997, Doyle et al. 1998 Counsell et al. 2006). Several recurring observations can be made: In the past the preparation of the interactive 3D models usually required extensive and time-consuming data pre-processing, there is often a trade-off between realness and interactivity (Appleton and Lovett 2003), and although a high potential is seen in the technology for e-participation and e-government applications (e.g., Wang et al. 2007), it only plays a marginal role in practice. With the increasing availability of 3D city models this is likely to change in the future. Planning and land management applications in the urban environment can now make use of the existing 3D city models, which considerably reduces implementation effort and costs. A key issue in this context is to research how 3D city models can be enhanced in order to support communication processes, decision-making, information of the public, and 3D analysis. Besides methods for the integration of spatial and georeferenced information, the usefulness and usability of the enhanced 3D city models has to be examined as well. To accomplish this a thorough cooperation and continuous exchange between research team and stakeholders in practical urban land management is necessary and is ensured through meetings, workshops and the utilization of a prototypic 3D Land Information System in planning processes within the city centre of Potsdam, Germany.

2 Study Area and System Specifications

The prototype 3D Land Information System presented was applied for a use case based in the city centre of Potsdam, Germany (cp. Figure 5), and covers an area of about five square kilometres. The 3D city model used as a base model is composed out of 1,304 buildings in LOD2, 50 buildings modelled in LOD3, and a digital terrain model with 3 m ground resolution. An aerial image with 25 cm ground resolution is used as terrain texture and trees and road lights are integrated as 3D symbols in .3ds format. Into this basic 3D city model, whose specifications correspond to several other 3D city models built in Germany in the recent years, further spatial and geo-referenced information (e.g., environmental data, master plans, development plans and construction plans) has been integrated.

The system development is based on LandXplorer Studio technology from Autodesk, a 3D geo-visualization solution with capabilities to create very large 3D landscape and city models from geo-data and 3D models from computer-aided design software (CAD). In addition to LandXplorer Studio Professional, which was used for authoring and managing the prototypic 3D Land Information System, ArcGIS from ESRI was used for geo-processing, SketchUp 6 Professional for 3D modelling, and Adobe Photoshop CS3 for image processing. A workstation with an Intel Xeon quad-core processor, 4 GB RAM, and a GeForce 8800 GTX graphic processing unit (GPU) was used for processing the data and assembling the 3D Land Information System and a Dell XPS Laptop with dual core Intel processor, 2 GB RAM, and a GeForce 7950 GTX GPU was used for presentations and collaborative planning meetings.

3 Methods

Stakeholder meetings with administration officers, architects, investors, and land owners were held regularly to select relevant spatial information for integration into the 3D city model. The integration of spatial information was implemented by the use of established methods in 3D geovisualization (e.g. terrain textures, 3D symbols, 3D modelling) and development of new methods for the transformation of plans to 3D plan representations. The primary aim was to research methods for creating visual representations of the selected spatial information within the 3D city model. Moreover, methods for the integration and access of further information and data assigned or related to the spatial information were researched as well. The resulting enhanced 3D city models were used and evaluated in further meetings. During these meetings, which included formal meetings with decision-makers and informal workshops and presentations with administration officers, architects, investors, and land-owners, comments and discussions on usability issues, data processing needs, potential applications, and data representation were recorded.

3.1 Integration of Geodata

In general two types of geodata are distinguished: raster data and vector data. Both data types can be integrated into the 3D city model by draping them over the digital terrain model (e.g., Döllner 2005). Besides this method, further methods for the integration of vector data exist, such as visualizing point features as 3D symbols or extruding polygons to 3D blocks. The methods and workflow applied for the integration of geodata are described for exemplary geodata sets.

3.1.1 Integration of Data on Protected Areas

Data on protected areas for nature conservation or groundwater protection are stored as geo-vector data in the environmental department of the city administration of Potsdam. The attribute tables hold information on the protection status, the name of the protected area, the date of designation, the legal basis for the designation, and more. Figure 1 depicts three approaches used to visually represent data on protected areas within the 3D city model.

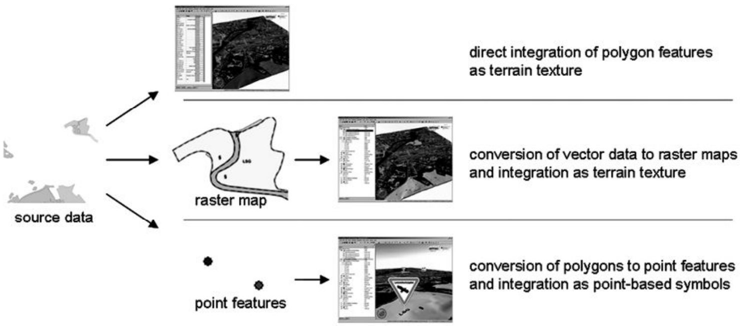

Fig. 1. Integration methods for geo-vector data (from top to bottom): direct integration of geo-vector data, integration as raster map, and integration as 3D symbols positioned inside the source polygons.

The first method is the *direct integration* of the geo-vector data into the 3D city model as interactive terrain texture by projecting the vector features onto the terrain. Interactive in this context means that rule-based and interactive queries can be used to access attribute information and create selections.

The second method, *integration as raster map*, uses geo-coded maps processed from the original vector data by using methods from digital cartography (e.g., colouring features, using signatures and text labels). The geo-coded raster maps derived from this are integrated as terrain textures.

A third approach, *integration as 3D symbols*, was used to integrate 3D symbols by converting the source data (polygon features) into point features. Icons showing official signs used in Germany were applied as 3D symbols placed at the point locations to visually communicate what type of protected areas is depicted. The three methods were applied to nature protection areas, protected biotopes and water protection areas.

3.1.2 Integration of Water Areas

Land-use data from the digital cadastre map was used to select water areas and integrate them as CityGML *WaterObjects* into the 3D city model. Therefore, the selected features were transformed and written to a CityGML file. The support of the CityGML specification enables the 3D city model authoring system to interpret the data and to use a *water shader* on it. A shader in the field of computer graphics is a software instruction, which is used by the GPU to create advanced rendering effects, such as simulating a realistic water surface (Kegel and Döllner 2007). To avoid visual artefacts from z-buffer fighting the digital terrain model was modified and areas covered by water were lowered.

3.2 Integration of Plans from Urban Planning

Several planning processes took place and are still continuing in the study area. So far, three different kinds of plans were examined: master plans, development plans, and construction plans. Although these plans can be differentiated with respect to their content and scale, they are similar in that they describe proposed / possible changes in the cityscape. Thus, the integration of visual representations into 3D city models will have to include changes in the three-dimensional model space. Therefore, methods for the creation of 3D plan representations are examined.

In contrast to geodata, most plans selected for integration were not georeferenced and it was not possible to integrate them directly into the 3D city model. Moreover, information about plan objects, such as the number of floors of a proposed building, is not encoded in attribute tables but in the plan graphics. For this reason, a number of pre-processing steps were necessary to create 3D plan representations from the plans examined. In the worst case, where only image files were available as source data, they had to be geo-coded first and plan features had to be digitized before further models could be made.

3.2.1 Integration of Master Plans

The integration of master plans is exemplified with the master plan '*Speicherstadt'*. The Speicherstadt is an old warehouse and industry complex located at the river Havel in the city centre of Potsdam. Key issues in the planning process were the height concepts and the building density of the plan proposals. The master plan and plan versions were continuously integrated into the 3D Land Information System to provide visual simulations during the planning process.

Initially *extrusion-based modelling* was used to create interactive block models from building footprints and building height information as shown in Figure 2. To ensure an accurate height representation, the absolute building height above sea level is encoded in the geometry of the building footprints. With the in-build import functions of the authoring system block models were processed from this data, which can be interactively and rule-based queried, coloured, and textured. Moreover, the height of the block models can be manipulated and attributes can be edited. In order to include the proposed land-use concept in the 3D plan representation, the geo-coded raster plan was masked with the planning area and integrated into the 3D city model as terrain texture (cp. Figure 2).

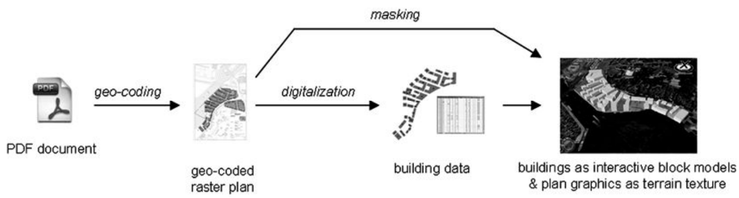

Fig. 2. Extrusion-based modelling approach used for the representation of master plans through block models and terrain textures.

The second method, *3D modelling*, was used to create 3D plan representations with more geometric and appearance detail in external applications. 3D modelling is an established method for creating architectural models and visualizations and it is very flexible in respect of geometry and appearance modelling. For this reason, it is possible to create realistic and comprehensive 3D plan representations which comprise not only the buildings but also the space around them including green spaces and trees, streets, open space, and city furniture. To facilitate 3D modelling, the plan features were classified into categories (buildings, transportation objects, and vegetation objects), and the height of the building above ground and the base height were added to the building footprints as attributes in the GIS environment. After this preparatory work, the features were exported from the GIS to the 3D modelling software. In-built functions of the export plug-in were configured to process block models from the building features and to level features based on attribute information. From this basic 3D model, a detailed model was created. The 3D models were imported via .3ds format and proper positioning was ensured using the centre point of the bounding box as a positioning vector. Figure 3 illustrates the 3D modelling approach.

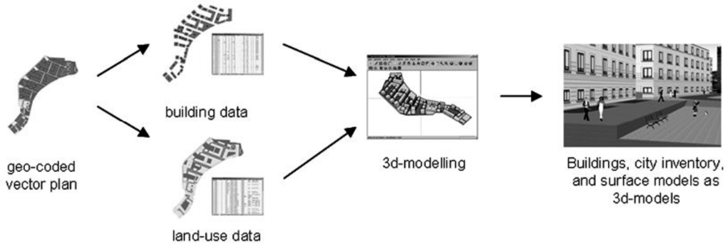

Fig. 3. 3D modelling approach used for the creation of detailed plan representations as 3D models.

A third modelling method, *CityGML-based modelling*, was developed to create a CityGML-based 3D plan representation. The aim behind this approach was to: a) develop a method for the (semi-)automated conversion of plans into CityGML-based 3D representations in order to b) store plans in a CityGML-based 3D geo database. The building data and the land-use data prepared for the 3D modelling method were used as source data. To represent the CityGML object properties in the data, the object classification is refined and additional attributes were specified for the land-use data as shown in Table 1.

The conversion of the land-use data was implemented through an interpolation with a triangulated irregular network followed by a data transformation from ESRI multipatch features to CityGML objects, as illustrated in Figure 4. Citygml4j, a Java class library developed by the Institute for Geodesy and Geoinformation Science at the Berlin Institute for Technology (IGG 2008), and GeoTools, an open source Java code library (geotools.codehaus.org), were used to implement the data transformation. In combination with building models in CityGML format, which were derived by exporting the building models created earlier by the use of the extrusion functions, a CityGML-based 3D plan representation was generated.

Table 1. Object classification used for the transformation of land-use data to a CityGML-based representation

Class	Attributes	Values
Transportation		
	transportation complex name	string
	transportation complex class	string
	transportation complex function	string
	function	string
	usage	string
	surface material	string
	colour	float [0…1], float [0…1], float [0…1]
Vegetation		
	function	string
	average height	float

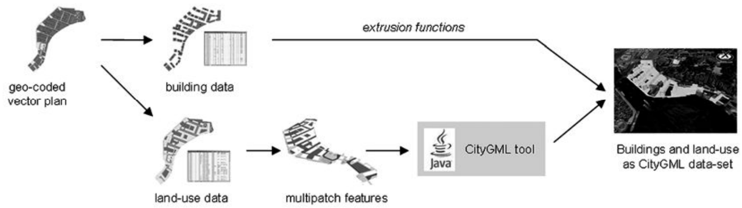

Fig. 4. Illustration of the CityGML-based modelling approach using data transformation and extrusion functions to convert plan features to a CityGML-based plan representation.

3.2.2 Integration of Development Plans

The second category of plans examined was development plans. In Germany, development plans are legally binding planning documents which specify the future land use as well as the building density and building functions. As the content and graphics of development plans are specified by law, the integration of the plan graphics as terrain texture was chosen as primary method.

To further communicate the potential effect of development plans on the cityscape, experiments were made to depict 3D building plots. Borders defining building plots were digitized and regulations about the maximum ground area, gross floor area, number of floors, maximum building height, and building function were added as attributes to the features. This data was used to create block models via extrusion functions, which represent

3D building plots. Transparency was deliberately added to 3D building plots to indicate that the visualization does not show actual or planned buildings, but the 3D space within which buildings can be constructed.

3.2.3 Integration of Construction Plans

Construction plans contain all necessary information to create detailed architectural or even in-door 3D models. Despite this fact, it was decided that these plans should be integrated as relatively simple LOD3 models to visually communicate the planning character and to keep the 3D modelling effort low. The workflow utilized is analogous to the 3D modelling approach employed earlier. The only difference was that in this case geo-coded site plans in Drawing Exchange Format (.dxf) could be used as source data for the modelling process.

The site plans only contained poly-lines and points, however. Thus, it was necessary to topologically correct the data and create a feature data set of the building footprints. These were prepared by adding attributes holding height information and exported to SketchUp (cp. 3.2.1, 3D modelling method). Ground plans and façade drawings, which have to be prepared to request permission for constructions in Germany, were used as a guideline for 3D modelling. The façade drawings were further used as façade textures to increase visual detail without modelling windows, doors, and other details. As described earlier, the integration of the 3D models into the 3D city model is done via .3ds format and positioning vectors.

3.3 Integrating further Information through Attributes, Actions, and Legends

The methods presented so far focus on the integration of visual representations of geodata and plans into the 3D city model. In many cases, these visual representations can already be considered to be interfaces for further spatial information, e.g., the direct integration of vector features as terrain textures allows features to be selected and their attribute information to be queried. In other cases, the information is encoded in the visual representation, e.g., geo-coded raster maps as terrain textures or 3D models. Thus, it is necessary to decide if a chosen visual representation is suitable to communicate the intended information and, if not, how the representation can be enhanced or whether further methods can be used to achieve the aim of communicating specific information. Within the project, three methods were used: integration of information as attributes, integration through actions, and integration through legends.

3.3.1 Information as Object Attributes

In the case of 3D modelling, attribute information, which was added to the data earlier, gets lost during data export and import processes. It is possible to add this information manually in the authoring system after the import process. However, this method is time-consuming and error-prone. For this reason, externally modelled 3D models of buildings were converted to CityGML using built-in functions of the authoring system, and a function was developed to transfers attributes from the source building footprints to the CityGML data based on a spatial join (location-wise). The same function was used to transfer address information and building data from the cadastre map to the buildings.

3.3.2 Information Integration through Actions

Most spatial information integrated during the system development was related to other data or consisted of several documents. This additional data and information was made available by linking digital media and applications to 3D labels and 3D symbols. The method was applied, amongst others, to link 3D plan representations to a prototype web-based plan information system, to start-up GIS projects underlying the prototypic 3D Land Information System, and to link plans to additional data sets (e.g., text files, plan documents in PDF format, and images).

3.3.3 Information Integration through Legends

If thematic raster data sets are used as terrain textures, it is necessary to provide legends to translate the depicted signatures, symbols, and colours into information. This can either be done by using an action which relates to a legend file, or by integrating the legend as an image overlayed onto the 3D city model. Therefore, legends were prepared and stored as images with the terrain textures. The same method was used to prepare legends for 3D representations of plans.

4 Results

The primary result is a prototypic *3D Land Information System* of the city centre of Potsdam, which contains visual representations of three master plans (and plan versions), four development plans, two construction plans, cadastre data, environmental data, and public transportation network data. A screenshot depicting the integrated plans is shown in Figure 5, while

Figure 6 shows examples of integrated environmental data and the use of symbols.

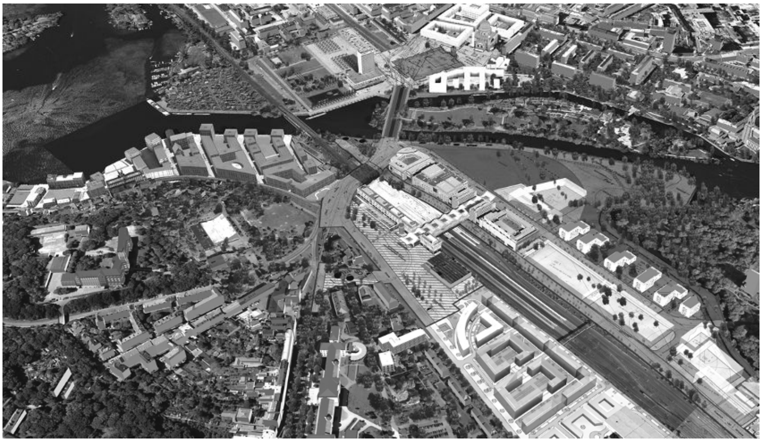

Fig. 5. Screenshot of the prototypic 3D Land Information System with integrated planning data (from top left clock-wise): 1. Master plan 'Speicherstadt' as extruded buildings and terrain texture; 2. Master plan 'Alter Markt' and development plan 'Landtagsneubau'; 3. Development plan 'Babelsberger Strasse' and construction plans for the residential building plots; and 4. Master plan 'Reichsbahnausbesserungswerk'.

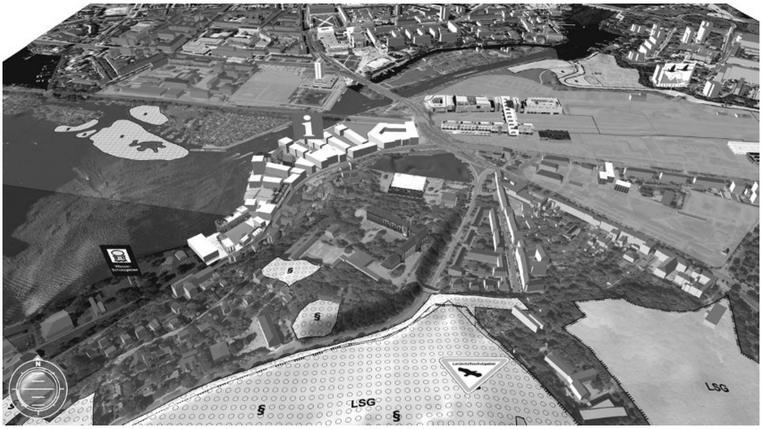

Fig. 6. Screenshot of the prototypic 3D Land Information System with integrated geodata including nature protection areas as raster-based terrain texture, water protection areas and polluted land cadastre as vector-based terrain textures.

4.1 Results from the Integration Methods Applied to Geodata

The integration of geodata as terrain texture is straightforward, and both methods – the direct integration of vector data and the integration of raster maps derived from vector data – resulted in an increase of information intensity of the prototypic 3D Land Information System. The results of these two methods must be differentiated, however. As can be observed from Figure 6, the integration of raster-based maps can be used to apply methods from cartography to visually communicate information included in the original source data. In contrast, the direct integration of vector data only allows us to apply colours and transparency. The vector features and attributes can be manually and rule-based selected, however, which increases the user's options to interact with the data. Moreover, the method can be combined with the use of 3D symbols to visually communicate the type of data represented by the vector features. Besides the integration of environmental data presented in this contribution (cp. Figure 6), further geodata such as land parcels, a topographic map, and public transportation network data have been integrated using the same methods.

4.2 Results from the Integration Methods Applied to Plans

In contrast to the integration of geodata, the integration of plans as 3D plan representations requires more data-processing effort. This is especially the case if only Adobe PDF documents or images are available as source data as was the case with the integrated master plans and development plans.

The first method applied to master plans, *extrusion-based modelling*, results in interactive block models, which were combined with terrain textures derived from the source plans as shown in Figure 7a. It is rated by stakeholders as being generally sufficient for communicating the basic idea of the planning proposal on the scale of master planning. Furthermore, it was rated as being especially useful for collaborative meetings because the building heights and appearance can be manipulated interactively.

The *3D modelling* approach, in contrast, results in a representation with more geometrical and appearance detail. In combination with additional 3D models (in the example a pier and two sailing boats) and the water shader applied to the water areas (cp. 4.1.2), a realistic representation is achieved, as shown in Figure 7b. Aside from the visual differences, the results of the two methods can be compared based on the included information. While the 3D modelling approach results in a gain of visual detail and a loss of attribute information, the extrusion functions for the generation of block buildings preserve attribute information assigned to the building data. The results of the 3D modelling approach were rated especially useful for presentations in meetings with decision-makers and for the promotion of projects.

Fig. 7. The left image shows the result from using extrusion functions to create interactive block buildings and the right image shows a plan representation derived from the 3D modelling approach combined with a water shader.

The third method, *CityGML-based modelling*, results in 3D plan representations whose visual appearance is comparable to the results from the extrusion-based modelling method. However, the 3D representation contains much more semantic information. This can be attributed to the fact that the land-use concept is represented through objects, which are specified according to the CityGML-specification. Thus, it is generally possible to assess the fraction of vegetation areas, transportation areas, and building areas and whereby determine urban planning indicators. Furthermore, it is possible to define several appearance models for one data set as shown in Figure 8.

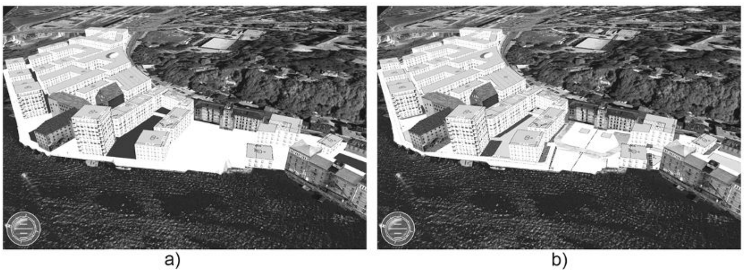

Fig. 8. The images show the results from the CityGML-based modelling approach for master plans; the left image shows the plan representation as a CityGML data set without a defined appearance for the land-use objects, while in the right image the plan graphics was used to texture the objects.

In Figure 8a, no further textures or colours are applied to the land-use objects (the green colour is automatically assigned to CityGML vegetation objects by the system), while in Figure 8b the original raster plan was applied as a texture. Besides this flexibility with respect to the appearance, attributes assigned to the source plan features during the plan creation process are maintained and the data can be transferred to a CityGML-based database.

To include development plans within the 3D Land Information System, plans were integrated as terrain textures and transparent 3D building plots were created. The integration as terrain texture ensures that the plan graphic, which is specified by law, is maintained (cp. Figure 9a), while the transformation of the graphical elements into 3D representations of building plots visually communicates an idea of the spatial effect the plan might develop (Figure 9b). Additionally the 3D building plots can be queried to access further information assigned in the modelling process, such as maximum building height, maximum number of floors, or the maximum gross floor area. Thus the use of a 3D representation for building plots increases the interactivity and information intensity of the system.

Fig. 9. Representation of development plans as: a) terrain texture; and b) transparent 3D building plots

The integration results of the third plan category, construction plans, are depicted in Figure 10. Through the use of the documents needed to request construction permissions, the 3D models were modelled and textured (less than one hour per building). Their integration into the model, in combination with the corresponding development plan, efficiently communicates that a building permission has been submitted. Furthermore, it can be visually assessed, if the application fits into the building plots.

Fig. 10. Representation of construction plans through 3D models

4.3 Results from Integrating Information through Attributes, Actions, and Legends

The methods of integrating further information as attributes, through actions, and through legends as overlay images, result in a further increase of interactivity and information intensity of the system. The results of the integration as attribute information were briefly mentioned in the context of the conversion of master plans to a CityGML data set and the integration of 3D building plots. Both examples increase the information value of the model and enable querying information. Furthermore, the integration of address information into the system enables users to search for a location based on an address.

Actions assigned to 3D labels or 3D objects also raise the information value of the system as they can be used to access external applications and databases directly from the visual interface. This functionality was used to link the integrated plans to a prototype web-based planning information system, which includes further information and documents associated with the plans such as plan documents, press announcements, and architectural drawings.

The integration of legends as image overlay is useful and elementary. It enables users to decode the information contained in raster-based terrain textures. Figure 11 shows the use of overlay images to integrate legends, and illustrates the concept of using actions to link labels to external applications.

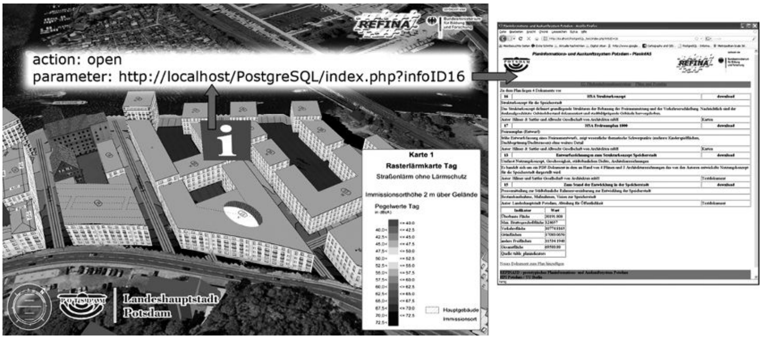

Fig. 11. Actions were used to relate 3D labels and 3D symbols to external applications such as web-based information portals and overlay images were used to integrate legend information into the 3D display.

4.4 Results from the Utilization of the System in Planning Processes

Although neither questionnaires nor extensive stakeholder analyses have been conducted so far, some preliminary results regarding usefulness and usability can presented. The system has proven to be very useful for visually assessing the height concepts of the master plan Speicherstadt in stakeholder meetings. The system was also used to present an agreed height concept to decision-makers, and in presentations and meetings with architects, investors, and authorities. In general, the responses from these stakeholder groups were positive. Several authorities within the administration are currently surveying the potential for future applications and discussing how the system can be permanently integrated into the information and communication infrastructure of the city administration. Moreover, several potential applications were formulated by different stakeholder groups, as shown in Table 2.

Table 2. Potential and implemented applications envisioned by different stakeholder groups

Stakeholder	Potential functionalities	Implemented
Authorities	- visual access to environmental data	+
	- presentation & visual assessment of planning pro-	+
	posals	(+)
	- city & business promotion	-
	- (public) participation meetings and web-service	-
	- process simulations and analyses (wind, shadows,	
	etc.)	
Architects	- source of 3D data as basic planning information	-
	- environment to integrate planning proposals	+
Project de-	- promotion of projects	(+)
velopers	- visual comparison of planning alternatives	+
	- visual interface to project data and database	-

+......implemented within the project
-.......not implemented so far
(+)...implemented through images and videos used by project partners

5 Discussion

This contribution shows how 3D city models can be applied and enhanced towards complex 3D Land Information Systems by integrating heterogeneous spatial information. The resulting system can be used to effectively support urban land management processes.

To implement such a system in a sustainable way, thorough modelling and integration strategies are needed. Within the administration and planning professionals, 3D city modelling expertise is still limited. Thus, system implementation requires a close cooperation and exchange of the involved stakeholders at the administrative, organizational and technical levels. Only if planning documents are made available by architects and engineers as geo-coded vector plans or geo-referenced 3D models does a continuous, systematic update of the underlying database become possible. In our case, a first step into this direction has been initiated by the city administration of Potsdam by formulating a directive, which requires planners to hand in geo-coded plans. Moreover, a GML-based standard for development plans in Germany (Benner and Krause 2007) is going to be adopted by the city of Potsdam. Since these development plans are GML-based, object-orientated, and geo-coded, they can be transformed to 3D representations and integrated into the system automatically. The utilization of an agreed data standard whereby ensures development security for the involved stakeholders. A comparable agreement for the digital exchange of 3D construction plans between administration and private companies and citizens respectively, could be used to automate the update of the 3D city model database.

To make full use of the system's potential, it will be advantageous to establish a direct connection to the spatial data infrastructure of the city, automating the integration of (geo-)data through services such as web map services or web feature services; such functionality has been demonstrated by Döllner and Hagedorn (2007). Transactional web feature services might also be used to provide access to the system for external users, such as architects and engineers, to enable collaborative use of the base 3D city model for planning issues. Of course, this would require secure connections, a user management system, and digital rights management to ensure the integrity of the system.

While most technology aspects could be identified and solved, organisational and human factors are still crucial. It would be necessary to adapt administrative processes and workflows and to train employees. Furthermore, acceptance of the system is not guaranteed. For example, the building conservation authority in Potsdam did not trust the height simulations, which were prepared for the master plan 'Speicherstadt' so an in situ simulation had to be conducted by the fire department. Only after this simulation drew the same results as the virtual simulation, the system's acceptance increased.

In summary, our thesis that 3D city models provide an innovative framework and medium for integrating and communicating heterogeneous spatial information in the context of urban land management is well supported. Nevertheless, many technological and organizational challenges, such as creating versions of models and their automatic, and systematic updating through communal business processes, remain unsolved. Moreover, further user and acceptance studies will be necessary.

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References

Appleton, K. & A. Lovett (2003): GIS-based visualization of rural landscapes: defining ‚sufficient' realism for environmental decision-making. In: Landscape and Urban Planning, Vol. 65, pp. 117-131.

Benner J. and Krause K.U. (2007) Das GDI-DE Modellprojekt XPlanung. Erste Erfahrungen mit der Umsetzung des XPlanGML-Standards. In: Schrenk, M. (Ed.) REAL CORP 2007: To Plan is not Enough: Strategies, Concepts, Plans, Projects and their Successful Implementation in Urban, Regional and Real Estate Development; Proc. of the 12th Internat. Conf., Vienna, pp. 379-388.

Cartwright, W., Pettit, C., Nelson, A. & M. Berry (2005): Community Collaborative Decision-Making Tools: Determining the Extent of 'Geographical Dirtiness' for Effective Displays. Proceedings of the 21st International Cartographic Conference, 9-16th July, A Coruna, Spain.

Counsell J., Smith S. and Richman A. (2006): Overcoming some of the issues in maintaining large urban area 3D models via a web browser. In: Proceedings of the information visualization, pp 331-336, DOI 10.1109/IV.2006.82

Danahy J. W. (2005): Negotiating public view protection and high density in urban design. In: Bishop, I. & Lange, E. (eds.): Visualization in Landscape and environmental planning – Technology and Applications. Taylor & Francis, Oxon, UK.

Döllner J. (2005): Geovisualization and Real-Time 3D Computer Graphics. In: Dykes J., MacEachren A.M. and Kraak M.-J. (eds.): Exploring Geovisualization. Elsevier, Oxford, UK.

Döllner J. and Hagedorn B. (2007) Integrating Urban GIS, CAD, and BIM Data By Service-Based Virtual 3D City-Models. Online: http://cgs.hpi.uni-potsdam.de/publications/Public/2007/DH07/udms_2007_doha_draft.pdf, Last date accessed 12.11.2007.

Doyle S., Dodge M. and Smith A. (1998): The Potential of Web-Based Mapping and Virtual Reality Technologies for Modelling Urban Environments. Computers, Environment and Urban Systems, Vol. 22, No. 2, pp. 137-155.

Gröger G., Kolbe T.H., Czerwinski A. and Nagel C. (2008): OpenGIS City Geography Markup Language (CityGML) Encoding Standard, Version 1.0.0, International OGC Standard, Open Geospatial Consortium, Doc. No. 08-007r1, 2008.

Haala N. and Brenner C. (1999) Extraction of buildings and trees in urban environments. In: ISPRS J. Photogrammetry & Remote Sensing, Vol. 54, pp. 130-137, 1999.

Institute for Geodesy and Geoinformation Science (2008): citygml4j; java classes for handling CityGML data-sets, download and information: http://opportunity.bv.tu-berlin.de/software/projects/show/ citygml4j, last accessed 2008/12/10.

Kegel A. and Döllner J. (2007): Photorealistische Echtzeit-Visualisierung geovirtueller Umgebungen. In: Mitteilungen des Bundesamtes für Kartographie und Geodäsie 2007.

Kolbe T. H. (2009): Representing and Exchanging 3D City Models with CityGML. In: Lee J. and Zlatanova S. (Eds.): 3D Geoinformation Sciences. Springer Verlag, Berlin Heidelberg.

Lange E. and Hehl-Lange S. (2005): Future Scenarios of Peri-Urban Green Space. In: Bishop, I. & Lange, E. (eds.): Visualization in Landscape and environmental planning – Technology and Applications. Taylor & Francis, Oxon, UK

Ranzinger M. and Gleixner G. (1997): GIS Datasets for 3D Urban Planning. Computers, Environment and Urban Systems, Vol. 21, No. 2, pp 159-173.

Richman A., Hamilton A., Arayici Y., Counsell J. and Tkhelidze B. (2005) Remote Sensing, LIDAR, automated data capture and the VEPS project. In: Banissi et al. (eds): Proc. of the 9th Intl. Conference on Information Visualisation, London, pp 151-156, DOI 10.1109/IV.2005.106

Rottensteiner F., Trinder J. and Clode S. (2005) Data acquisition for 3D city models from LIDAR – Extracting buildings and roads. Geoscience and Remote Sensing Symposium, 2005, Proceedings. IEEE International Volume 1, DOI 10.1109/IGARSS.2005.1526226

Wang H., Song Y., Hamilton A. and Curwell S. (2007) Urban information integration for advanced e-Planning in Europe, Government Information Quarterly (2007), doi:10.1016/j.giq.2007.04.002

Wilson, T. (2008): OGC KML, Version 2.2.0, International OGC Standard, Open Geospatial Consortium, Doc. No. 07-147r2, 2008.